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(54) **AIRLESS TIRE CONSTRUCTION HAVING MULTIPLE LAYERS**

(71) Applicant: **Bridgestone Americas Tire Operations, LLC**, Nashville, TN (US)

(72) Inventor: **Robert Asper**, Wadsworth, OH (US)

(73) Assignee: **Bridgestone Americas Tire Operations, LLC**, Nashville, TN (US)

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(51) **Int. Cl.**

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B60C 7/14	(2006.01)
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B33Y 80/00	(2015.01)

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CPC ***B60C 7/14*** (2013.01); ***B29D 30/02*** (2013.01); *B33Y 80/00* (2014.12); *B60C 2007/146* (2013.04)

(58) **Field of Classification Search**

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See application file for complete search history.

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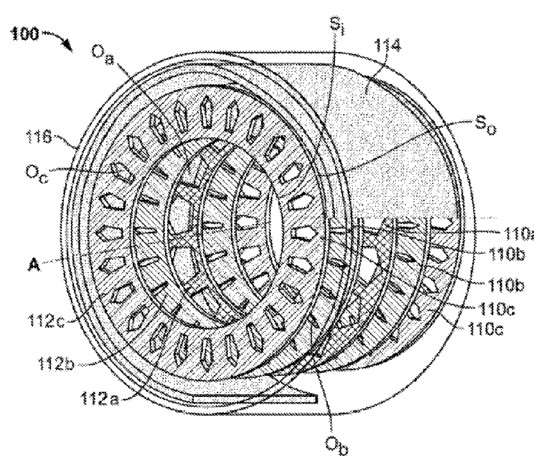
Primary Examiner — John Walters
Assistant Examiner — James Triggs
(74) *Attorney, Agent, or Firm* — Bridgestone Americas Tire Operations, LLC

(57) **ABSTRACT**

An airless tire has a wheel portion and a webbing extending from the wheel portion towards an axis of rotation of the airless tire. The diameter of an annular outer surface of the wheel portion varies along an axial direction of the airless tire.

25 Claims, 4 Drawing Sheets



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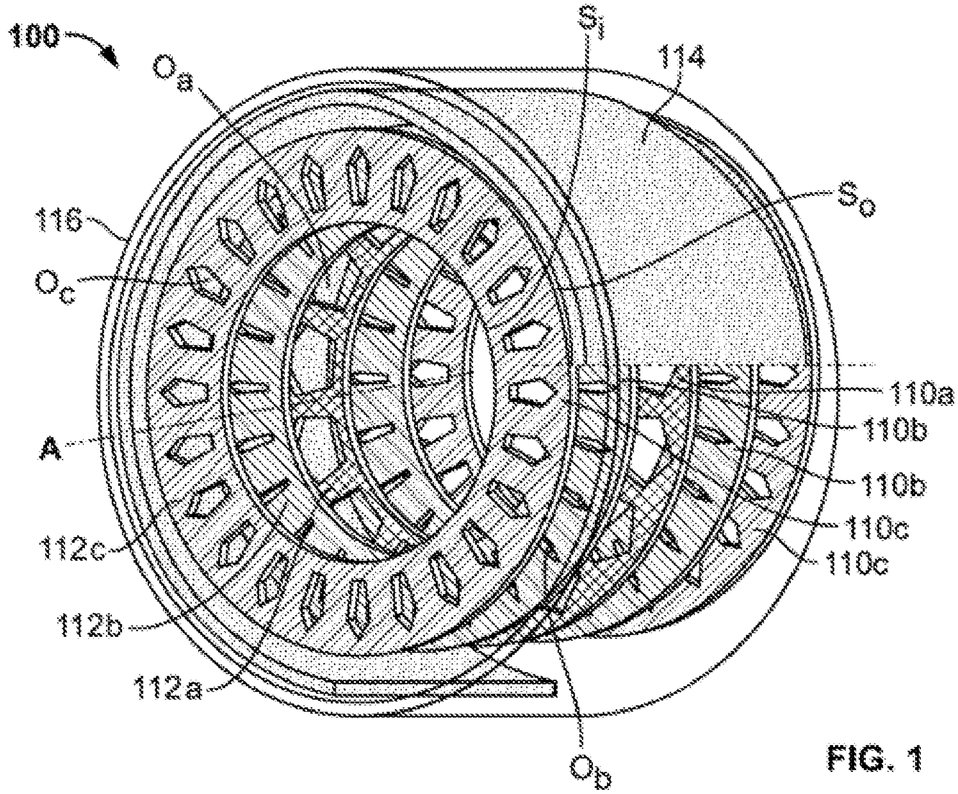
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S_i
114
116
O_c
S_o
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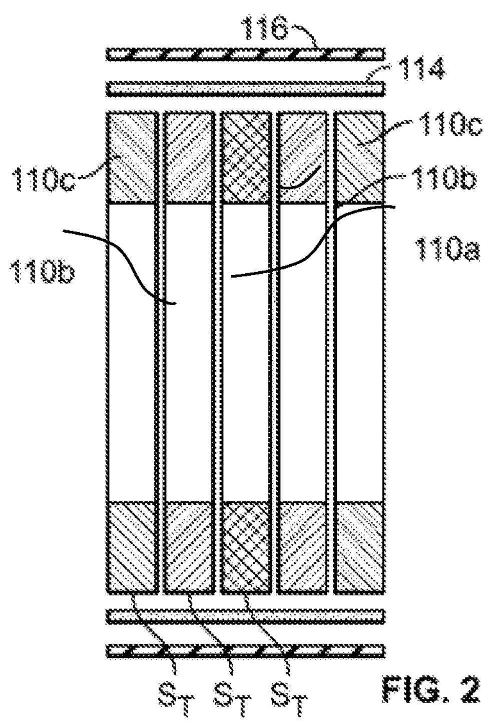
110b
110b
110c
110c
A
112c
112b
112a
O_b

FIG. 1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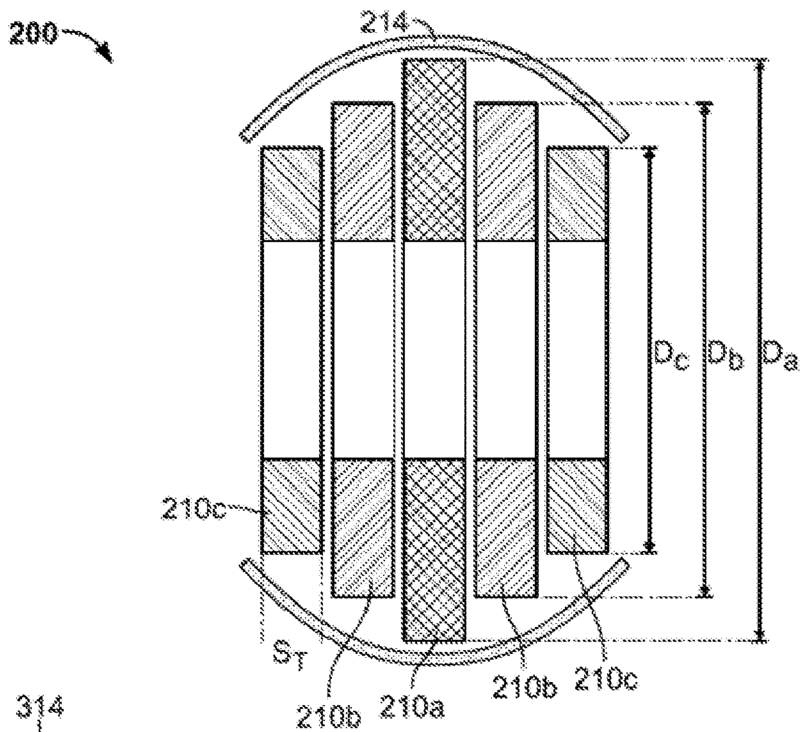
110c
110b
110b
110a
S_T
S_T
S_T

FIG. 2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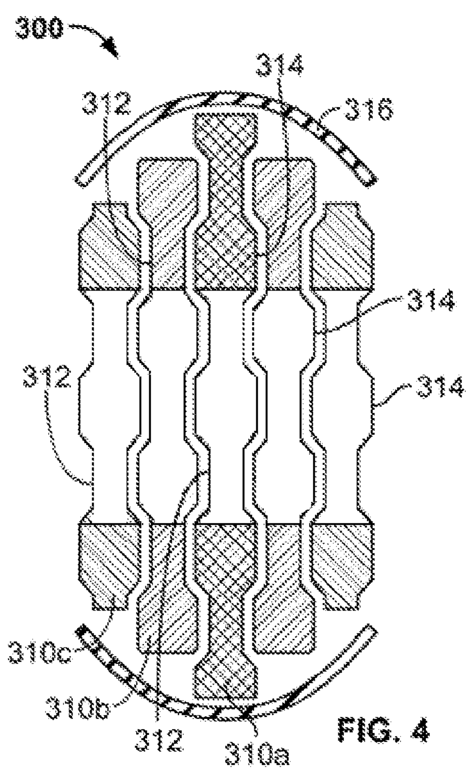
D_b
D_a
210c
S_T
210b
210a
210b
210c

FIG. 3


300
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312
316
314
312
314
310c
310b
312
310a

FIG. 4

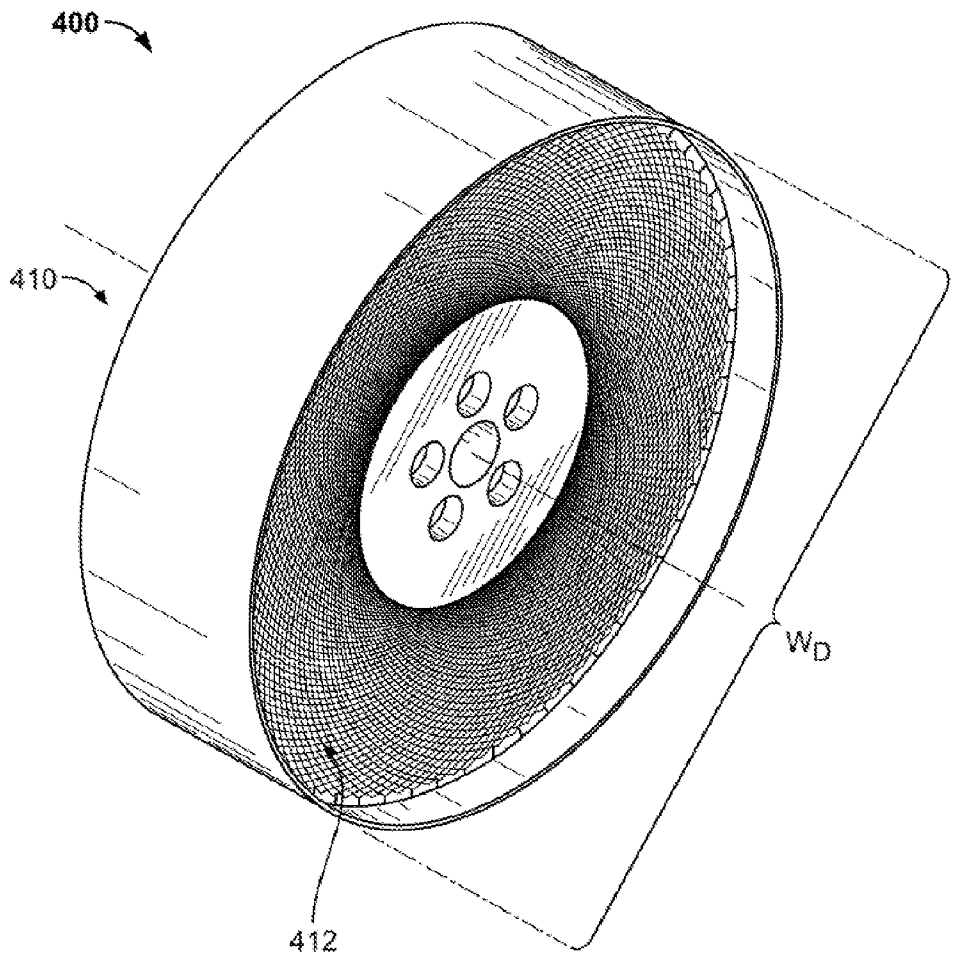

FIG. 5

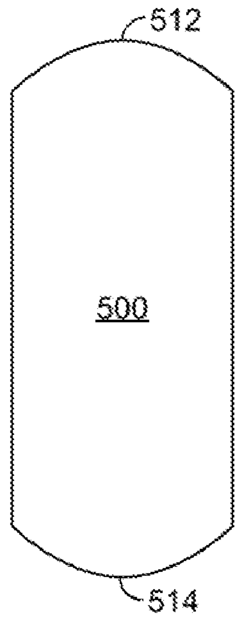

FIG. 6

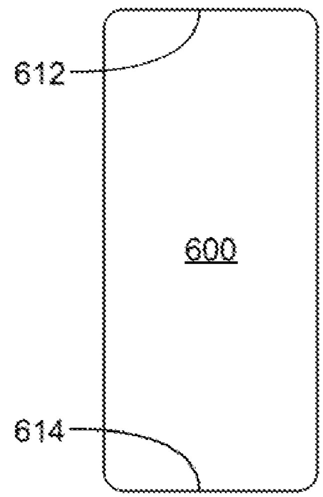

FIG. 7
(Prior Art)

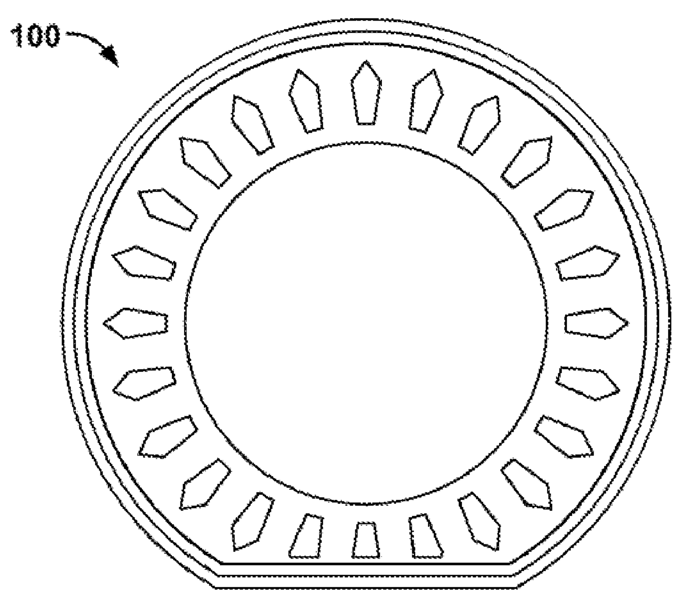

FIG. 8

AIRLESS TIRE CONSTRUCTION HAVING MULTIPLE LAYERS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/572,996, filed on Dec. 17, 2014, which claims priority from U.S. Provisional Patent Application No. 61/920,528, filed on Dec. 24, 2013. The disclosure of these applications is incorporated by reference herein in their entirety.

FIELD OF INVENTION

The present disclosure relates to an airless tire. More particularly, the present disclosure relates to an airless tire having varying attributes.

BACKGROUND

Airless, or non-pneumatic tires known in the art include spokes or spoke rings each having the same stiffness and the same diameter. These prior art spokes buckle or deflect upon contact with the ground, and create a contact patch shape with substantially straight leading and trailing edges. These prior art spokes may be constructed of a material that is relatively stronger in tension than in compression, such that when the lower spokes buckle, the load can be distributed through the remaining portion of the wheel.

SUMMARY

In one embodiment, an airless tire includes a plurality of spoke rings, including adjacent first and second spoke rings, each having an annular outer surface and an annular inner surface with a plurality of spokes extending between the outer and inner surfaces. In this embodiment, the first spoke ring has a different diameter from the second spoke ring, and a tread layer extends circumferentially around the outer surfaces of the spoke rings. Further, the spoke rings may be attached to a hub that, when loaded, causes the spokes above the hub to be tensioned and causes the spokes below the hub to be compressed, and the tensile and compression forces may be equal in magnitude. The airless tire may also include a shear band disposed about the outer annular surfaces of the spoke rings. The tire may form a contact patch shape with a rounded leading edge when a load is applied to the tire. The first and second spoke rings may have different stiffnesses. Additionally, the tire may include a third spoke ring that includes a plurality of spokes, wherein the spokes of the third spoke ring may not be aligned with the spokes of the first spoke ring along an axis of rotation of the tire. Finally, the spoke rings may be made from a material selected from the group consisting of corded carbon-filled rubber, nylon, polyester, glass or aramid fibers with resin, thermoplastic, and urethane.

In another embodiment, a tire comprises a wheel having an axis of rotation and an annular outer surface. The distance between the axis of rotation and the annular outer surface of the wheel varies along an axial direction. The tire further includes a webbing extending from an annular inner surface of the wheel portion towards the axis of rotation. The tire further may include a shear band on the outer annular surface of the wheel portion, wherein the webbing in the lower region of the wheel portion may be compressed and the webbing in an upper region of the wheel may be tensioned when the wheel is loaded. A stiffness of the webbing may vary along an axial direction, and the webbing may be attached to a hub in the center of the tire. The webbing may further comprise a plurality of spoke rings, and the tire may form a contact patch shape with a rounded leading edge. Finally, the webbing may be formed by an additive manufacturing process.

In yet another embodiment, a non-pneumatic tire comprises a plurality of spoke rings, including a first spoke ring between second and third spoke rings. The spoke rings include annular outer and annular inner surfaces and a plurality of spokes extending between the outer and inner annular surfaces. The first spoke ring has a first outer diameter and the second spoke ring has a second outer diameter different from the first outer diameter, and the third spoke ring has a third outer diameter approximately equal to the second outer diameter. The tire may also include a tread portion covering an outer surface of the plurality of spoke rings. The first spoke ring may further include a first spoke region having a first thickness and a second spoke region having a smaller second thickness. Further, the second spoke ring may include a third spoke region with a third thickness and a fourth spoke region with a fourth thickness, where the third thickness may be greater than the fourth thickness and where the first spoke region abuts the fourth spoke region, and wherein the second spoke region abuts the third spoke region. The first spoke ring may have a first stiffness and the second spoke ring may have a second different stiffness, and the third spoke ring may have a third stiffness approximately equal to the second stiffness. A shear band may be included on the outer annular surfaces of the spoke rings, where the spokes in the lower regions of the spoke rings may compress and the spokes in the upper regions of the spoke rings may be tensioned by the shear band when a load is placed on the tire. Finally, the compression and tension forces may be approximately equal in magnitude.

In still another embodiment, a non-pneumatic tire comprises a hub able to be coupled to a machine, the hub having a rotational axis about which the tire is configured to roll. A support structure including an inner circumferential portion associated with the hub and an outer circumferential portion radially spaced from the inner circumferential portion is further included. The support structure extends between opposed, axially-spaced side edges of the tire, and the support structure includes a plurality of cavities. The tire further includes a tread portion associated with the outer circumferential portion, wherein the support structure includes layers of elastomeric material having opposing faces lying in opposing planes substantially perpendicular to the rotational axis. Finally, some of the layers include apertures that correspond to the cavities, and the layers are chemically bonded together.

BRIEF DESCRIPTION OF DRAWINGS

In the accompanying drawings, structures are illustrated that, together with the detailed description provided below, describe exemplary embodiments of the claimed invention. Like elements are identified with the same reference numerals. It should be understood that elements shown as a single component may be replaced with multiple components, and elements shown as multiple components may be replaced with a single component. The drawings are not to scale and the proportion of certain elements may be exaggerated for the purpose of illustration.

FIG. **1** is a schematic drawing showing a perspective view of one embodiment of an airless tire **100** having multiple spoke rings;

FIG. **2** is a schematic drawing illustrating a cross-section of the airless tire **100**;

FIG. **3** is a schematic drawing illustrating a cross-section of an alternative embodiment of an airless tire having multiple spoke rings of varying diameter, stiffness, and thickness;

FIG. **4** is a schematic drawing illustrating a cross-section of another alternative embodiment of an airless tire having multiple spoke rings of varying diameter, stiffness, and thickness, with each spoke ring having convex and concave portions;

FIG. **5** is a perspective view of still another alternative embodiment of an airless tire, having a unitary wheel portion and webbing;

FIG. **6** is a schematic drawing illustrating an exemplary rounded contact patch shape made by an airless tire, where the contact patch shape has a rounded leading edge and a rounded trailing edge;

FIG. **7** is a schematic drawing illustrating an exemplary contact patch shape of a prior art tire, where the footprint has a flat leading edge and a flat trailing edge; and

FIG. **8** is a schematic drawing illustrating a side view of the airless tire **100** bearing a load.

DETAILED DESCRIPTION

The following includes definitions of selected terms employed herein. The definitions include various examples or forms of components that fall within the scope of a term and that may be used for implementation. The examples are not intended to be limiting. Both singular and plural forms of terms may be within the definitions.

"Axial" and "axially" refer to a direction that is parallel to the axis of rotation of a tire.

"Circumferential" and "circumferentially" refer to a direction extending along the perimeter of the surface of the tread perpendicular to the axial direction.

"Equatorial plane" refers to the plane that is perpendicular to the tire's axis of rotation and passes through the center of the tire's tread.

"Tread" refers to that portion of the tire that comes into contact with the road under normal inflation and load.

FIG. **1** illustrates one embodiment of an airless tire **100** having an axis of rotation A passing through its center. Airless tire **100** is constructed of five spoke rings **110**, including a central spoke ring **110***a*, a pair of intermediate spoke rings **110***b* disposed on each side of the central spoke ring **110***a*, and a pair of outer spoke rings **110***c* disposed on either side of intermediate spoke rings **110***b*. Each of the spoke rings **110** includes a plurality of spokes **112**. While five spoke rings are shown in the illustrated embodiment, it should be understood that the airless tire **100** is not limited to any particular number of spoke rings, and may alternatively utilize structures other than spoke rings, such as a unitary structure having a plurality of spokes. The spoke rings **110** may be constructed of materials including, without limitation, corded carbon-filled rubber, nylon, polyester, fibers (glass, aramid, etc.) with resin, thermoplastic, or urethane.

Each spoke ring **110** each has an inner annular surface S_I and an outer annular surface S_O that defines an inner diameter and a maximum outer diameter, respectively. In the illustrated embodiment, the maximum outer diameters of all five spoke rings **110** are equal. In alternative embodiments, the maximum outer diameters of the spoke rings may vary.

In the illustrated embodiment, each spoke **112** extends from the inner annular surface S_I to the outer annular surface S_O of the respective spoke ring **110**. The spokes **112** define openings O_S between one another. For illustrative purposes, the openings O_S are shown as pentagon-shaped. However, it should be understood that the openings O_S may have any geometric shape. In an alternative embodiment (not shown), the spokes may form a more complex webbing rather than extend from the inner annular surface S_I to the outer annular surface S_O.

Each spoke ring **110** has a stiffness k. As one of ordinary skill in the art would understand, the stiffness of a spoke ring may be defined by a number of factors, including, without limitation, the material of the spoke ring and the geometry of the spokes and openings. Spoke rings with a higher stiffness are more resistant to deformation and compression. In one embodiment, central spoke ring **110***a* has a first stiffness k_a, intermediate spoke rings **110***b* each have substantially the same second stiffness k_b, and outer spoke rings **110***c* each have substantially the same third stiffness k_c. In one embodiment, the second stiffness k_b is greater than the first stiffness k_a, and the third stiffness k_c is greater than both the first stiffness k_a and the second stiffness k_b. In an alternative embodiment, the first stiffness k_a is greater than both the second stiffness k_b and the third stiffness k_c, and the second stiffness k_b is greater than the third stiffness k_c. In another alternative embodiment, the second stiffness k_b is greater than both the first stiffness k_a and the third stiffness k_c, and the third stiffness k_c is greater than the first stiffness k_a.

With continued reference to FIG. **1**, the central spoke ring **110***a* is shown as having a relatively lower number of spokes **112***a*, with the spokes **112***a* being separated by relatively larger openings O_a. As one of ordinary skill in the art would understand, this geometry would result in a relatively low first stiffness k_a. This low first stiffness k_a may be achieved by other means, such as with the use of different materials, construction methods, or geometries.

Intermediate spoke rings **110***b* are shown as having more spokes **112***b* than central spoke ring **110***a*. The spoke openings O_p of intermediate spoke rings **110***b* are narrower than spoke openings O_a located within central spoke ring **110***a*. Additionally, spokes **112***b* of intermediate spoke rings **110***b* are thicker than spokes **112***a* of central spoke ring **110***a*. Both intermediate spoke rings **110***b* have the same geometry and the same stiffness k_b. One of ordinary skill in the art would understand that this geometry would result in a relatively higher stiffness k_b than the central spoke ring stiffness k_a. Alternatively, the intermediate stiffness k_b of spoke rings **110***b* may be achieved by other means, such as with the use of different materials, construction methods, or geometries for intermediate spoke rings **110***b*.

Outer spoke rings **110***c* are shown in FIG. **1** as having more spokes **112***c* than intermediate spoke ring **110***b*, with spokes **112***c* being separated by relatively larger openings O_c than those of the intermediate spoke ring openings O_b. In this embodiment, both outer spoke rings **110***c* have the same spoke geometry, and the same stiffness k_c. One of ordinary skill in the art would understand that the geometry of the outer spoke rings **110***c* and the larger relative size of the outer spoke ring openings O_c would cause the outer spoke rings **110***c* to have a lower stiffness than intermediate spoke rings **110***b*. Alternatively, the stiffness k_c of outer spoke rings

110*c* may be achieved by other means, such as with the use of different materials, construction methods, or geometries for spoke rings **110***c*.

In the illustrated embodiment, the five spoke rings **110** have three different stiffnesses. In the illustrated embodiment, the intermediate spoke rings **110***b* have the highest stiffness, and the central spoke ring **110***a* has the lowest stiffness. It should be understood that any number of spoke rings having any number of different stiffnesses may be selected. After the stiffnesses of the spoke rings have been selected, the spoke rings are arranged in a desired manner, suitable to a particular application. For example, the stiffness of each ring may be selected to produce a tire having desired characteristics, such as low noise, low vibrations, or low rolling resistance.

When airless tire **100** is placed in contact with the ground in a load-bearing condition, airless tire **100** contacts the ground to form a tire contact patch shape (not shown in FIG. **1**). Because the airless tire contact patch shape will be dictated by the stiffness of the spoke rings **110**, in addition to other factors, a design engineer can alter the contact patch shape of the airless tire by varying the stiffness of the spoke rings **110** across the width of the airless tire. This could be done to produce a curved leading edge of the contact patch shape that is desirable when concerned with ride harshness and impact isolation. Further stiffness changes can be used to optimize the contact patch shape for off-highway tires, reducing soil compaction, a key design parameter for certain applications.

FIG. **1** depicts the spokes **112** of corresponding like spoke rings **110** being arranged in alignment with one another. For example, the spokes **112***c* and openings O_c of each outer spoke ring **110***c* are aligned with each other, and the spokes **112***b* and openings O_b of each intermediate spoke ring **110***b* are aligned with each other. In an alternative embodiment, the spokes **112** and openings O_S of corresponding like spoke rings are not in alignment with each other. It will be apparent to one of ordinary skill in the art that various alignments of spoke rings **110** will cause airless tire **100** to have different performance properties. When spoke rings **110** are not aligned with each other, spokes **112** of similar spoke rings **110** enter the contact patch shape area at a different time when airless tire **100** is rolling. The spoke rings **110** may also be aligned such that each spoke **112** of the all spoke rings **110** enters the contact patch area at a different time when airless tire **100** is rolling. One of ordinary skill in the art would be able to select an alignment providing desired performance properties in any particular application.

After the spoke rings **110** are arranged in a desired manner, they are affixed to a non-pneumatic hub (not shown), using known affixing means. Exemplary affixing means include, without limitation, welding, brazing, and the application of adhesive. A high annular strength band **114** is then circumferentially attached about the spoke rings **110**. The high annular strength band acts as a structural compression member on the airless tire **100**, and increases interlaminar shear strength across the axial length of the airless tire **100**. As one of ordinary skill would understand, the high annular strength band **114** could include an elastic center portion, sandwiched between two inelastic outer portions, or be composed of a single composite structure (see prior art U.S. Pat. No. 5,879,484). The high annular strength band **114** may also be referred to as a "shear band" or "band." In an alternative embodiment, the high annular strength band may be omitted.

A tire tread **116** is then wrapped about the high annular strength band **114**. The tire tread **116** may include elements, such as ribs, block, lugs, grooves, and sipes as desired to improve the performance of the tire in various conditions.

FIG. **2** shows a cross-section of airless tire **100**. As can be seen from this view, each spoke ring **110** of airless tire **100** has the same thickness S_T. In alternative embodiments (not shown), the spoke ring thickness of spoke rings may vary. By varying thicknesses S_T, the contact patch shape created by airless tire **100** may be adapted to suit a wide range of applications, including agricultural and passenger applications.

FIG. **3** illustrates a cross section of an alternative embodiment of an airless tire **200**. In this embodiment, spoke rings **210** have different maximum outer diameters and different stiffnesses k. The spoke rings **210** in this embodiment have inner diameters D_1 that are substantially the same. Each spoke ring **210** may have a unique stiffness k, or may have a common stiffness k with one or more other spoke rings **210**. In this embodiment, central spoke ring **210***a* has a first stiffness k_a, intermediate spoke rings **210***b* each have a second stiffness k_b, and outer spoke rings **210***c* each have a third stiffness k_c. In one embodiment, the first stiffness k_a is lower than both the second stiffness k_b and the third stiffness k_c. Additionally, the second stiffness k_b is lower than the third stiffness k_c. In an alternative embodiment, the first stiffness k_a is greater than both the second stiffness k_b and the third stiffness k_c, and the second stiffness k_b is greater than the third stiffness k_c. In another alternative embodiment, the second stiffness k_b is greater than both the first stiffness k_a and the third stiffness k_c, and the third stiffness k_c is greater than the first stiffness k_a.

Each spoke ring **210** may have a unique outer diameter, or may have a common outer diameter with one or more other spoke rings **210**. In the illustrated embodiment, central spoke ring **210***a* has a first maximum outer diameter D_a, intermediate spoke rings **210***b* each have a second maximum outer diameter D_b, and outer spoke rings **210***c* each have a third maximum outer diameter D_c. The first maximum outer diameter D_a is greater than the second maximum outer diameter D_b, which in turn is greater than the third maximum outer diameter D_c. It should be understood that any number of spoke rings having any number of different outer diameters may be employed. After the outer diameters of the spoke rings have been selected, the spoke rings are arranged in a desired manner, suitable to a particular application. For example, the outer diameter of each ring may be selected to produce a tire having desired characteristics, such as low noise, low vibrations, or low rolling resistance.

Use of variable diameter spoke rings allows for a curved or toroidal band (or shear band) to be used in this type of non-pneumatic tire ("NPT") design. The toroidal band allows additional deflection needed to maximize tire contact patch area. This is especially important for off-highway or agricultural tires which need a contact patch shape with a greater area to minimize soil compaction.

In the illustrated embodiment, each spoke ring **210** has a constant outer diameter. In alternative embodiments (not shown), the spoke rings may have variable outer diameters. For example, the outer diameter of each spoke ring may vary in the axial direction, such that when the spoke rings are assembled, the assembly has a smooth, curved outer surface.

Each spoke ring **210** may have a unique thickness, or may have a common thickness S_T with one or more other spoke rings **210**. Tread **214** is wrapped around the outer surfaces of spoke rings **210**. In an alternative embodiment (not shown), a high annular strength band is disposed between the outer surfaces of the spoke rings and the tread.

FIG. **4** illustrates a cross section of another alternative embodiment of an airless tire **300**. The tire **300** is substantially similar to the tire **200** discussed above, except for the differences identified below.

In this embodiment, each spoke ring **310** has concave portions **312** and convex portions **314** that alternate along the sides of spoke rings **310**. When aligned, the concave portions **312** and convex portions **314** of adjacent spoke rings **310** abut each other, as seen in FIG. **4**. This configuration may provide increased rigidity and support among the spoke rings **310**. Alternatively, spoke rings **310** may include other structures that adjoin to one another, such as protrusions in one spoke ring and depressions to receive the protrusions in another spoke ring. Tread **316** circumferentially surrounds spoke rings **310**.

FIG. **5** illustrates a perspective view of yet another alternative embodiment of an airless tire **400**. In the illustrated embodiment, the airless tire **400** has a single wheel portion **410**. Wheel portion **410** may be a single unitary structure, or may be made up of a plurality of spoke rings **110** fused together. Wheel portion **410** has a webbing **412** instead of spokes that extend from an inner annular surface to an outer annular surface. The webbing **412** may be any pattern or shape sufficient to provide support. The maximum outer diameter W_D of wheel portion **410** may vary along an axial direction. For example, the maximum outer diameter may be greater in an equatorial plane and smaller towards the sides of airless tire **400**.

The stiffness k of the webbing portion **412** may vary along an axial direction of wheel portion **410**. A varying stiffness k throughout wheel portion **410** can be achieved in several ways. In one embodiment, several spoke rings **110** having various stiffnesses k are fused together. In an alternative embodiment, different materials are used in the wheel portion **410** during manufacture to create pre-stresses within the wheel portion. In another alternative embodiment, the webbing has varying geometry in an axial direction, which causes the stiffness to vary in the axial direction. The webbing geometry may be varied through molding or machining processes, or by a 3D printing or additive manufacturing process. Those of ordinary skill in the art will understand that other methods known in the art may be used to provide a varying axial stiffness within wheel portion **410**.

In the embodiment shown in FIG. **5**, non-pneumatic hub **414** is affixed to the center of webbing **412** using known affixing means. Exemplary affixing means include, without limitation, welding, brazing, and the application of adhesive. Non-pneumatic hub **414** can be attached to a vehicle in a similar manner as a wheel in a conventional tire. In other embodiments, additional webbing **412** can be used instead of non-pneumatic hub **414**.

The spoke rings and webbing disclosed in the embodiments of FIGS. **1-5** may cause the airless tire **100**, **200**, **300**, **400** to form a rounded contact patch shape when in contact with the ground. The rounded contact patch shape reduces the effects of road impact and noise. The curvature of the rounded contact patch shape can be determined by various factors, including, without limitation, each spoke ring's stiffness, outer diameter, thickness, spoke geometry, number of spokes, shape and number of openings, and the number of spoke rings included in airless tire. By varying these parameters, the airless tire may be adapted to suit a wide range of applications, including agricultural applications and passenger vehicle applications. For example, in some applications such as use in agricultural vehicles, uniform contact pressure and maximized contact area may be desired. An airless tire with a rounded contact patch shape (or rounded band) can be designed to deflect more at low loads maximizing contact area and minimizing soil compaction. An airless tire with flat contact patch shape loses the ability to deflect in the radial direction at different rates across its axial width which will cause less deflection, and less contact patch area, especially at light load conditions. An airless tire with a rounded contact patch shape will result in superior (reduced) soil compaction performance and superior (reduced) ride harshness for the driver/operator.

FIG. **6** depicts an exemplary elongated rounded contact patch shape **500** which is formed when one of the airless tires **100**, **200**, **300**, **400** is in contact with a rolling surface in a load bearing condition. Elongated rounded contact patch shape **500** includes a rounded leading edge **512** and a rounded trailing edge **514**. The axial stiffness distribution or varying axial diameter of the airless tires **100**, **200**, **300**, **400** contribute to the forming of rounded edges **512** and **514**.

By contrast, FIG. **7** depicts a contact patch shape **600** of a prior art airless tire (not shown). The contact patch shape **600** includes straight leading and trailing edges **612**, **614**. An airless tire making a flat contact patch shape **600** results in greater ride vibration and noise than an airless tire making a rounded contact patch shape **500**.

The contact patch shape is formed when the airless tire is in contact with a rolling surface in a load bearing condition. As one example, FIG. **8** is a schematic drawing depicting a side view of the airless tire **100** of FIGS. **1** and **2** bearing a load. In one embodiment, the effects of using variable stiffness rings in axial alignment can be enhanced based on the load distribution within the airless tire. The load carrying distribution in such an embodiment can rely more heavily on load transmitted in compression through the spokes at the bottom of the tire (between the load and the ground surface), and less on the shear band to transfer load to the top of the tire. In some NPTs the load is carried primarily through the use of a cylindrical shear band with spokes that buckle at the bottom of the tire. These NPTs are considered "top loaders" and carry most of the load through the shear band and the upper spokes in tension. Other NPTs are essentially rigid (or semi-flexible) structures that carry a majority of the load through the bottom portion, "bottom loaders." In one embodiment, the load is relatively balanced between the spoke rings and shear band such that approximately 50% of the load is carried through the bottom spokes in compression and approximately 50% of the load is carried through the shear band and upper spokes in tension. This approximate 50/50 load distribution allows for varying the diameters and stiffness of the spoke rings to create a desired contact patch shape. In this embodiment, the spokes **112** undergoing a compressive force do not buckle when airless tire **100** is loaded.

The airless tire **100** creates a rounded contact patch shape **500** on a rolling surface when a load is placed on airless tire **100**. Rounded leading edge **512** is formed when airless tire **100** undergoes a loading force. Rounded leading edge **512** result in reduced ride vibration and noise by allowing the tire to pass over bumps in the road more softly than an airless tire with a straight leading edge.

To the extent that the term "includes" or "including" is used in the specification or the claims, it is intended to be inclusive in a manner similar to the term "comprising" as that term is interpreted when employed as a transitional word in a claim. Furthermore, to the extent that the term "or" is employed (e.g., A or B) it is intended to mean "A or B or both." When the applicants intend to indicate "only A or B but not both" then the term "only A or B but not both" will be employed. Thus, use of the term "or" herein is the inclusive, and not the exclusive use. See, Bryan A. Garner, A Dictionary of Modern Legal Usage 624 (2*d*. Ed. 1995). Also, to the extent that the terms "in" or "into" are used in the specification or the claims, it is intended to additionally mean "on" or "onto." Furthermore, to the extent the term "connect" is used in the specification or claims, it is intended to mean not only "directly connected to," but also "indirectly connected to" such as connected through another component or components.

While the present application has been illustrated by the description of embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the application, in its broader aspects, is not limited to the specific details, the representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of the applicant's general inventive concept.

What is claimed is:

1. An airless tire, comprising:
- a plurality of spoke rings, including a first spoke ring adjacent to a second spoke ring,
  - wherein each of the plurality of spoke rings includes an annular outer surface, an annular inner surface, and a plurality of spokes extending between the outer and inner annular surfaces,
  - wherein the first spoke ring has a first outer diameter and the second spoke ring has a second outer diameter different from the first outer diameter; and
- a tread layer extending circumferentially around the annular outer surfaces of the plurality of spoke rings.

2. The airless tire of claim **1**, wherein the spoke rings are attached to a hub, and wherein when a load is applied to the hub, the spokes positioned below the hub are compressed and the spokes positioned above the hub are tensioned.

3. The airless tire of claim **2**, wherein the tension and compression forces are approximately equal in magnitude.

4. The airless tire of claim **1**, further comprising a shear band disposed about the outer annular surfaces of the spoke rings.

5. The airless tire of claim **1**, wherein the tire forms a contact patch shape with a rounded leading edge when a load is applied to the tire.

6. The airless tire of claim **1**, wherein the first spoke ring has a first stiffness and the second spoke ring has a second stiffness different from the first stiffness.

7. The airless tire of claim **1**, further comprising a third spoke ring,
- wherein the third spoke ring includes a plurality of spokes, and
- wherein the spokes of the third spoke ring are not aligned with the spokes of the first spoke ring along an axis of rotation of the airless tire.

8. The airless tire of claim **1**, wherein the spoke rings are made from a material selected from the group consisting of corded carbon-filled rubber, nylon, polyester, glass or aramid fibers with resin, thermoplastic, and urethane.

9. A tire, comprising:
- a wheel portion having an axis of rotation,
  - wherein the wheel portion includes an annular outer surface, and
  - wherein a distance between the axis of rotation and the annular outer surface varies along an axial direction; and
- a webbing extending from an annular inner surface of the wheel portion towards the axis of rotation.

10. The tire of claim **9**, further comprising a shear band attached to the outer annular surface of the wheel portion, and wherein the webbing in a lower region of wheel portion is compressed and the webbing in an upper region of the wheel portion is tensioned by the shear band when a load is placed on the tire.

11. The tire of claim **9**, wherein a stiffness of the webbing varies along the axial direction.

12. The tire of claim **9**, wherein the webbing is attached to a hub in the center of the tire.

13. The tire of claim **9**, wherein the wheel portion and webbing comprise a plurality of spoke rings.

14. The tire of claim **9**, wherein the tire forms a contact patch shape with a rounded leading edge.

15. The tire of claim **9**, wherein the webbing is formed by an additive manufacturing process.

16. A non-pneumatic tire, comprising:
- a plurality of spoke rings, including a first spoke ring disposed between a second spoke ring and a third spoke ring,
  - wherein each of the plurality of spoke rings includes an annular outer surface, an annular inner surface, and a plurality of spokes extending between the outer and inner annular surfaces,
  - wherein the first spoke ring has a first outer diameter, the second spoke ring has a second outer diameter different from the first outer diameter, and the third spoke ring has a third outer diameter approximately equal to the second outer diameter; and
- a tread portion covering an outer surface of the plurality of spoke rings.

17. The non-pneumatic tire of claim **16**, wherein the first spoke ring has a first spoke region having a first thickness and a second spoke region having a second thickness, the first thickness being greater than the second thickness,
- wherein the second spoke ring has a third spoke region with a third thickness and a fourth spoke region with a fourth thickness, the third thickness being greater than the fourth thickness,
- wherein the first spoke region abuts the fourth spoke region, and
- wherein the second spoke region abuts the third spoke region.

18. The non-pneumatic tire of claim **16**, wherein the first spoke ring has a first stiffness, the second spoke ring has a second stiffness different from the first stiffness, and the third spoke ring has a third stiffness that is approximately equal to the second stiffness.

19. The non-pneumatic tire of claim **16**, further comprising a shear band attached to the outer annular surfaces of the spoke rings, wherein spokes in lower regions of spoke rings compress and spokes in upper regions of spoke rings are tensioned by the shear band when a load is placed on the non-pneumatic tire.

20. The non-pneumatic tire of claim **19**, wherein the compression and tension forces are approximately equal in magnitude.

21. A non-pneumatic tire comprising:
- a hub configured to be coupled to a machine, the hub having a rotational axis about which the tire is configured to roll;
- a support structure including an inner circumferential portion associated with the hub and an outer circumferential portion radially spaced from the inner circumferential portion, the support structure extending

between opposed, axially-spaced side edges of the tire, wherein the support structure includes a plurality of cavities; and

a tread portion associated with the outer circumferential portion, wherein the support structure includes a plurality of layers of elastomeric material each having opposing faces lying in opposing planes substantially perpendicular to the rotational axis,

wherein at least some of the layers include apertures corresponding to the cavities, and

wherein the layers are chemically bonded to one another.

22. The tire of claim **21**, wherein at least some of the layers are annular layers having a centrally located aperture through which the hub is received.

23. The tire of claim **21**, wherein at least two adjacent layers each include respective cavity forming apertures, and wherein the cavity forming apertures correspond to at least a portion of a cavity.

24. The tire of claim **21**, wherein an interface is present between adjacent layers of elastomeric material, and the interface includes a chemical bond between the adjacent layers.

25. The tire of claim **21**, wherein the layers are adhesively bonded to one another.

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